

STATEMENT OF WORK

TITLE: Field Test Electrocoagulation for Accelerated Clean Up of the Northeastern Chromium Plume in the 100-D Area

KEY PROJECT TEAM MEMBERS

Project Manager (CAM): Ron Jackson
Technology Lead: Scott Petersen
DOE-RL: Mike Thompson
Project Engineer: TBD
Design Lead: Ron Clements
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Project Control: Deborah Whitt
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1.0 BACKGROUND INFORMATION

Groundwater beneath the 100-D Area is contaminated with hexavalent chromium. Hexavalent chromium was added to reactor cooling water to inhibit corrosion. Multiple leaks and spills of sodium dichromate stock solution (hexavalent chromium) occurred in the 100-D Area during reactor operation (1944 to 1969). Continuing downward migration of residual hexavalent chromium in the vadose zone is assumed to account for the widely distributed and persistent groundwater plume beneath much of the 100-D Area (see Figure 1). Efforts have been underway since 1997 to reduce the release of chromium into the river using a pump-and-treat system and a permeable reactive barrier (In Situ Redox Manipulation –ISRM)).

Pump and treat operations are currently being conducted in two locations in the 100-D area. The initial system is located in the northeast portion of the plume and consists of 4 extraction wells (D8-53, D8-54A, D8-68, and D8-72). Extracted groundwater is transferred to the 100-H area pump and treat facility, where hexavalent chromium is removed using ion exchange media. The treated water is injected to the aquifer at 100-H. In 2004, a second pump and treat system was deployed at 100-D. This system, referred to as DR-5, extended the capture zone to the south in response to increasing hexavalent chromium concentrations in the aquifer. This new system utilizes an ion exchange medium which is capable of being regenerated on-site.

The Department of Energy, Richland Operations Office, has committed to accelerate cleanup of contaminated groundwater along the Columbia River. Part of the coordinated approach for acceleration is to increase the rate of pumping and treatment on the northeastern chromium plume at 100-D, injecting treated water near the proximal portion of the plume to help flush hexavalent chromium out of the aquifer. Volumes up to 500 gallons per minute (gpm) at hexavalent chromium concentrations up to 2000 µg/L will need to be treated. The current treatment systems will not be cost-effective for the flow rates and concentrations required for accelerated cleanup, so an alternative technology will need to be deployed.

Evaluation of several alternative technologies has shown that electrocoagulation (EC) holds promise for cost-effectively treating groundwater to the remedial action goal, which is $<20 \mu\text{g/L}$. The focus of this work will be to perform a treatment pilot study using electrocoagulation to evaluate the practicability of using this technology to expand the pump and treat system at 100-D.

There are three major objectives for testing the EC technology. They are to:

- Determine the operability, robustness, and treatment efficiency of an EC system
- Characterize volume and composition of waste for proper waste classification
- Obtain design data for scaling the process from a 50-gallon per minute (gpm) to a 500 gpm system

2.0 TECHNOLOGY DESCRIPTION

Electrocoagulation is a water treatment process that has been used to remove a variety of suspended solid and dissolved pollutants from aqueous solutions by directly applying an electric field to the waste stream and inducing coagulation either through charge neutralization or reduction and precipitation of dissolved components typically as hydroxides. Electrocoagulation typically utilizes a sacrificial anode of either iron (steel) or aluminum. As the anode corrodes, iron or aluminum cations are released into solution initiating the coagulation process typically forming hydroxide complexes. In the case of aluminum anodes, the introduction of aluminum cations performs the same function as using alum as a chemical coagulant/flocculant. Addition of positive cations neutralizes negative surface charges on suspended solids allowing them to coalesce with the hydroxide particles for flocculation and settling.

Using electrocoagulation to remove hexavalent chromium, and other heavy metals, involves reducing hexavalent chromium to its insoluble trivalent form and precipitating it as a hydroxide or oxy-hydroxide. Ferrous iron is known to readily reduce hexavalent chromium. Additionally, direct reduction of hexavalent chromium by contact with the surface of the cathode is another mechanism which may contribute to reduction and precipitation of trivalent chromium. A byproduct of the application of electrical potential to a water waste stream is the electrolytic decomposition of water resulting in the generation of hydrogen gas at the cathode and likely oxygen at the anode (or possibly chlorine or carbon dioxide depending upon concentrations and solution dynamics). For some contaminants the generation of gas bubbles is utilized to aid in the separation process similar to the use of dissolved air floatation. Advantages of electrocoagulation are that it does not require extreme pH conditions or adjustments, minimizes addition of chemicals, and may result in a significant reduction in solid waste generated.

An electrocoagulation treatment system is composed of three major parts:

- A reaction chamber, consisting of multiple charged plates through which the contaminated water passes. Some designs subject the water path to turbulence, which is purported to enhance the reaction process.
- The electrical system, composed of control electronics and transformers to convert AC to DC, which is required in most designs for the reaction plates

- A means to dewater the suspended solids. This is typically a clarifier and filter press for commercial operations, but could also be a pond in which the solids settle to the bottom

This technology is fairly simple, in that it does not contain any moving parts so operation is dependent mainly on a stable power supply to the electrodes. Maintenance of the system involves the occasional replacement of the electrodes and perhaps treating the electrodes and reaction chamber with an acid to remove accumulated corrosion.

In 2002, a bench top electrocoagulation unit was used to treat a sample of groundwater from the 100-D Area. This simple test demonstrated that the technology would remove chromium from a small amount of 100 Area groundwater.

Appendix A contains responses to comments and suggestions made by the DOE Peer Review Committee regarding this work.

3.0 DESCRIPTION OF WORK

This work includes the design/build/test of an EC water treatment system at the current DR-5 facility. This system will include up to a 50 gpm EC skid-mounted system, a means to remove suspended solids (e.g., vacuum clarifier), one or more extraction wells, and one new injection well.

The work includes all activities and costs associated with the project management, work planning, procurement, design, construction, monitoring, and waste management to test up to a 50 gpm EC system.

3.1 TASKS TO BE PERFORMED:

3.1.1 Task 1. Project Management

Task includes the labor for planning, management, supervision, safety meeting attendance, responding to specific DOE-RL requests, interfacing with DOE-RL and the regulators, and oversight of all activities.

3.1.2 Task 2. Work Plans

Task includes development of work plans (e.g. treatability test report, sampling and analysis plan (SAP), and waste management plan), and other internal planning documents necessary to guide field work. The treatability test plan, SAP, and waste management plan require regulator approval. The work plan contains the performance criteria for the EC test.

3.1.3 Task 3. Install well

Tasks include drilling a groundwater remediation well, conducting hydrogeologic testing as needed, providing management and labor support, and associated documentation (e.g. borehole summary report). Management of drill waste is included as part of this task.

3.1.4 Task 4. EC System/Building Modification/Balance of Plant Design

This task covers the labor and subcontractor to design the EC test system, building modification, and balance of plant. . Key documents include the design criteria, specifications, and drawings. Includes preparing the Statement of Work, Request for Proposal, and awarding the contracts. Two subcontracts are planned: one for a subcontractor to design and build the EC system and the other to complete the Balance of Plant tasks.

The extent of the design includes:

- Facility design and structural modification to the existing building,
- Conveyance pumping and piping system design
- Electrical service and distribution system upgrades
- Programmable Logic Controller (PLC)/operator interface software program changes
- Operator Interface Computer (OIC)/PLC upgrades and field modifications
- Design of injection or extraction wells (assumes some of the existing wells could be used to support the test)
- Testing of existing wells to determine well yield capacity

3.1.5 Task 5. Build/install EC unit and install Balance of Plant

This task includes the labor, materials, purchase of chemicals, and subcontracts to build the EC unit, modify the existing building, piping, electronics, and tie in to the injection and extraction wells.

3.1.6 Task 6. Conduct up to 50 gpm EC pilot field test

This task involves the labor and subcontract to conduct the EC field test (includes system testing, operating procedures, troubleshooting procedures, and process performance monitoring). The vendor for the EC system will support startup of the EC system, including providing drawings and procedures.

3.1.7 Task 7. Evaluation report

This includes the labor and subcontract cost to prepare the EC evaluation report. The contents of the report will meet the overall requirements of a treatability test report as described in EPA guidance document EPA/540/R-92/071a.

3.2 MAJOR DELIVERABLES

Deliverables	Date
Transmit Decisional Draft to RL Treatability Test Plan	8/22/06
Deliver EC skid to Hanford Site	12/18/06
Initiate EC Test	3/30/07
Transmit Evaluation Report (Decisional Draft) to RL	12/27/07

3.3 BASIS/ASSUMPTIONS

The following were used as guidance to formulate costs and schedules for this project. The schedule is presented in Figure 2. A summary of the budget is in Table 1.

- The project assumes that the authorization to proceed will be occur by May 1, 2006. If money is not authorized by May 1, 2006, the project assumes a day to day slip in the schedule.
- The scope of the estimate is to install an EC water treatment system at the current DR-5 facility. The system will include an EC skid mounted system and a system to remove solids from the water before injecting into the aquifer. Standard instruments and controls will be used to operate the injection and extraction wells and the pumps. A new 100 KVA electrical service will be added to the existing facility. The EC must be NRTL approved prior to shipment. The well network may include up to two extraction and two injection wells, depending on well field analysis.
- There are numerous explicit and implicit assumptions associated with testing a process. The considerations that follow summarize many of the obvious assumptions, but as work plan details are developed, additional factors are likely to surface.
 - The main process sludge consists of iron oxide, hydroxide or oxy-hydroxide that physically spalls (peels or separates) from the anode.
 - Some of the spalled iron oxide will accumulate at the bottom of the cell and will need occasional removal.
 - Relatively small amounts of Cr(VI), calcium carbonate, radionuclides, arsenic (if present in groundwater) and other anionic and cationic metals co-precipitate with ferric hydroxide or oxy-hydroxide that forms when ferrous iron becomes oxidized, either at the anode or by reaction with atmospheric oxygen.
 - Iron hydroxide (hydrous oxide or oxy-hydroxide) that precipitates from solution will partially float in association with gas bubbles from the electrodes.
 - Precipitates will also rise to the liquid surface in cells that operate in a hydraulic upflow configuration.
 - Dissolved ferrous iron will remain in solution in effluent from the electrocoagulation cell and will need to be removed before injecting the treated water into the subsurface formation.
 - Much of the uranium and technetium will co-precipitate when ferrous iron is oxidized to the ferric state and precipitates as ferric hydroxide (oxy-hydroxide or hydrous oxide).
 - Some of the nitrate will be reduced electrochemically at the cathode.
 - In electrocoagulation systems with close-spaced electrodes, Cr(VI) reduction at the cathode surface through contact or close proximity is a significant mechanism.
 - In electrocoagulation systems with wide-spaced electrodes, Cr(VI) reduction by chemical reaction with ferrous iron dissolved from the anode is the primary mechanism.
 - Cr(VI) reduction in the electrocoagulation process is controlled by ferrous iron, consistent with equations such as the one in *Environmental Science and Technology*, 1996, 30 1614-1617, so hydraulic residence times, residual ferrous

- iron concentrations and initial Cr(VI) concentration are a viable conceptual model.
 - The low conductivity of groundwater beneath Area 100-D will require electrocoagulation cells to operate at “higher-than-typical” voltage, or will require more than one cell in series to achieve Cr(VI) reduction.
 - Solid waste from electrocoagulation cells will contain iron-rich solids of two forms: one form will be dense solid that spalls from the electrode surfaces in sheets; and the other form will be a “floc-type” sludge typical of conventional iron coagulation systems.
 - Gasses produced from the electrocoagulation cell may contain hydrogen, carbon dioxide, oxygen, and chlorine.
 - Field optimization will be necessary to establish operating conditions that achieve the necessary reduction of Cr(VI) to Cr(III); *a priori* theoretical design calculations that predict the degree of Cr(VI) removal are not available.
- Other Assumptions:
 - Well construction will be done by a drilling subcontractor
 - Cost of the well drilling based on FY 2005 actuals
 - Subcontractor specializing in water treatment technology will be involved during planning and execution of the test
 - A subcontractor will be used to design and build the EC unit per performance specifications
 - Cost of the EC system based on vendor quote dated February 6, 2006
 - A general subcontractor will be used for electrical and mechanical for the Balance of Plant and tie in of the EC system to the injection and extraction wells
 - FH provides oversight, management, health and safety, and waste management resources
 - FH provide design for balance of plant (e.g. OIC, tie in)
 - FH provides existing facility (DR5) to house the EC technology
 - Assumes sole source procurement for the EC system in order to meet project schedule.
 - Assumes FH provide piping to well head.
 - Treatability tests will be performed by construction/engineering
 - Process waste will meets the Environmental Restoration and Disposal Facility (ERDF) disposal criteria and therefore will be disposed at ERDF
 - Assumes EC will operate under a Radiation Work Permit (RWP), as does D Area P&T. Labor will be similar to first six months of D Area P&T for sampling support and field operations testing.
 - Estimate excludes planning of resource overtime
 - Assumes waste management support will be similar to D Area Pump and Treat budget (risk factor: high-full year budget for used for waste management field testing support)
- The following process was used to develop the preliminary cost estimates for this project:
 - The estimate process began by identifying the steps required to perform the work described for this project.

- Assumptions were identified and activities were detailed into manageable tasks. Meetings were then conducted with management and engineering to validate tasks and assumptions
- The activities were resource loaded with the anticipated resources to accomplish the work. Labor was estimated by the CAM and engineering based on previous pump and treat operations. Material costs were based on previous experience dealing with the construction of pump and treat systems in the 100-D Area as well as discussions with potential vendors.

Project budget = \$2.2M

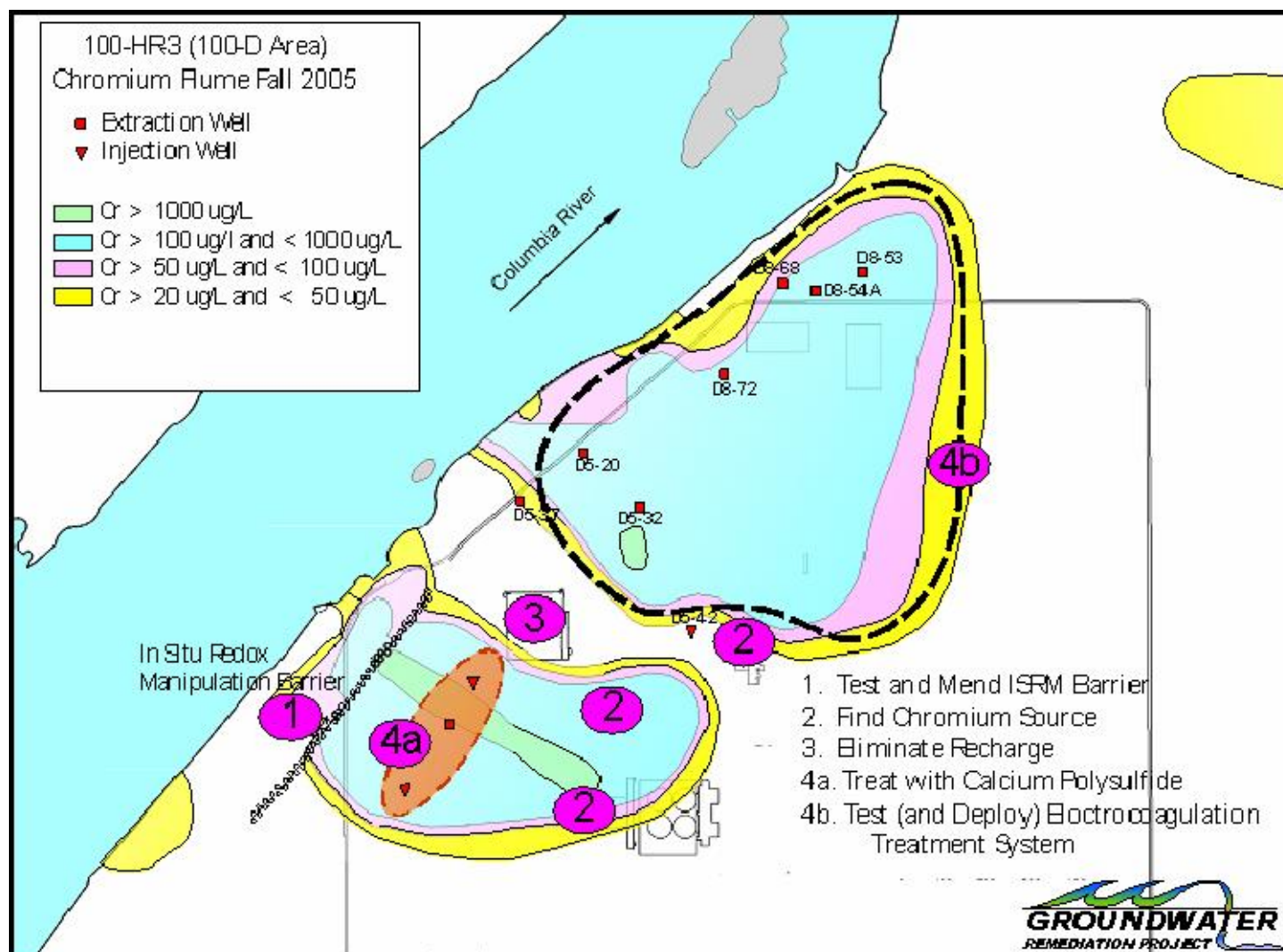


Figure 1. 100-D Area Location Map

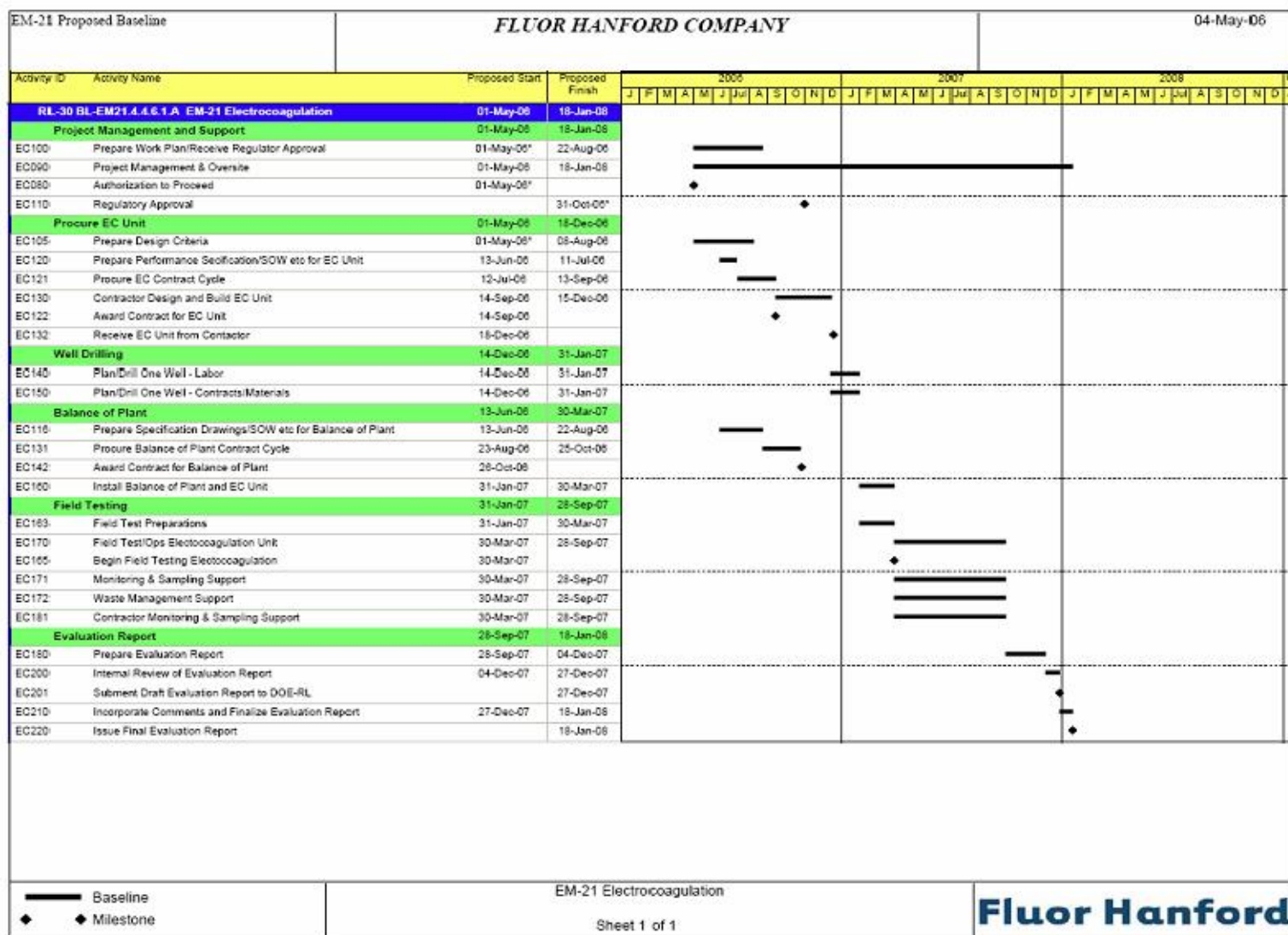


Figure 2. EC Implementation Schedule

Responses to Supplemental Columbia River Protection Activities Peer Review

Proposal Title: Inject Micron-sized Iron into the Deteriorating Portions of the ISRM Barrier

Technical Basis of the Proposal:

The panel believes the proposed project fits well into the systems approach to accelerate the cleanup of Cr(VI) contamination near the Columbia River. The project is based on valid and appropriate science

General technical issues for consideration:

- Electrocoagulation (EC) is a complex system, so designing for versatility is critical. The system should be robust enough to enable rapid adjustments in the field to allow the system to adapt to field conditions and to allow flexibility in operation. (see reviewers 2, 7, and 8)

Response: Comment noted. The project plans to engage vendors with EC expertise to help design/build the EC test skid.

- EC is scalable to the size of the plume area and is compact. If it is designed correctly, it can be used at one or at multiple sites. Coupled with re-injection, it may provide opportunities for “defense in depth;” (all reviewers)

Response: Comment noted.

- Consider recharge in the on site basin and other creative options for the treated water – The available options and ultimate use of the treated water should be a principal factor in the design since EC systems can be operated to yield a wide range of output water chemistries (e.g., targeted pH or eH levels) depending on needs. (see reviewers 2, and 7)

Response: The treated water will be used to inject (i.e., sweep) into wells upgradient of the extraction plumes, similar to the 100-H Area pump and treat.

- Vendor selection is of paramount importance; the panel recommends development of clear parameters for consideration during vendor selection. Don’t base vendor selection on treatability alone. (all reviewers)

Response: Comment noted.

- Because EC appears to be a simple technology, many vendors attempt to build and market systems. Some of these EC systems have been “oversold,” which may result in stakeholder confidence issues. (see reviewer 2)

Response: Comment noted.

- The panel provided several specific technical recommendations. These are summarized in a special box after the “Performance Metrics” below.

Response: Performance metrics/criteria will be documented in the treatability test plan/work plan.

- Perform a complete analysis of groundwater and effluent criteria to determine the end uses of water processed through the EC system. (see reviewers 2, 7, and 8)

Response: Agree.

- Consider reinjecting water passing through the EC system upgradient or into the contaminated basin, to integrate with the other proposed Cr(VI) treatment technologies.

Response: Treated water will be reinjected in wells upgradient from the extraction wells. This approach is consistent with the existing Record of Decision and the Remedial Design Report and Remedial Action Work Plan.

- The chemistry of the water coming out of the EC system, such as the pH and the ionic strength, is very important. If water has to be treated before reinjection, project costs will increase.

Response: Comment noted.

- More information about the flow rates is necessary to design an effective EC system.

Response: Hydrologic testing of existing and the new well is planned to support design of the EC tests. The initial test is planned at about 50 gpm to help evaluate if the EC technology can be deployed at the 100-D at higher volumes.

- Address the potential for formation of an impermeable oxide film on the cathode causing a decrease in system efficiency.

Response: Agree. This is one of the performance criteria that will be evaluated as part of this treatability test.

- Consider results from an “alternatives analysis” comparing ion exchange technology with EC and other treatment methods to determine the most effective and appropriate technology. (see reviewers 1,2,

Response: A subcontractor is currently preparing a technical document evaluating the EC and at least three other alternatives.

- Consider all applicable and viable alternative technologies.

Response: A subcontractor is currently preparing a technical document evaluating the EC and at least three other alternatives. Other alternatives are considered as we evaluate the final remedy. The EC test is part of the overall evaluation.

- Identify the impacts of increased pumping of groundwater.

Response: Agree. This will be evaluated in the treatability test report.

- Consider the production and disposal of solid waste “sludge” material in the various alternatives.

Response: Agree. This is an important criterion to be discussed as part of the EC test evaluation report.

- Consider the impact of the Hanford groundwater’s low conductivity on the function of an EC system.

Response: Comment noted. Hanford aquifer has relatively high dissolved solids and conductivity as compared to other aquifers.

Implementation Strategy:

- The sequence and timing of project activities are generally appropriate.

Response: Comment noted.

- Most vendors have a scoping process for process development and optimization based on site-specific water chemistry and effluent water quality needs. These scoping activities are normally performed for a very low cost. Working with that model, the overall project costs may be able to be reduced significantly (for example, eliminating some of the miscellaneous engineering hours associated with the onsite design). (see reviewer 2)

Response: Agree. The vendor can help in the scoping process and optimization. Engineering cost is required for the balance of plant items such as facility modification, well tie in, and process hardware/software.

- Although studies have documented that the historical costs for an EC system are relatively low compared to ion exchange, the total labor hours in those studies was higher for EC than other technologies -- thus, DOE labor rates are an important factor in the design and implementation and the panel recommends a system that can operate with minimal labor. Labor costs need to be optimized in order to make EC cost-effective. (see reviewer 7).

Response: Agree.

- Provide more detailed description of project management and engineering costs. The cost of this one technology test is currently 20% of the total congressional allocation, which seems very high when viewed as a water treatment cost. (see reviewers 2, 6, 7, and 8)

Response: Agree. The details on project management and engineering costs are developed further in the statement of work.

- The proposed project implementation schedule may be overly optimistic. Equipment procurement usually takes more than 8 weeks. (see reviewers 2, and 8)

Response: Comment noted.

- If the Department of Energy provides \$2 million to fund an EC project, it appears that scope could be included to optimize the pump and treat system and/or to consider other viable options. (all reviewers)

Response: The cost of this proposal covers the implementation of a small EC unit. The information, if the test is successful, will be used to upscale to a 400 to 500 gpm unit. These costs are covered in the FH Groundwater Remediation Project baseline. Optimization will be considered in the expansion of the EC system.

It is important to simultaneously optimize the pump and treat system when designing and locating the EC system, determining where to reinject or reinfiltrate recycled water, and where to identify the capture zones.

- Improve the conceptual model for how the EC system would operate.
- Evaluate alternative beneficial strategies for disposing of or reinjecting water passed through the EC system.
- Conduct the field test concurrently with efforts to identify infiltration zones, well placement, etc.
- Determine costs associated with solid waste disposal, power consumption, operation and maintenance, and discharge of treated water.
- If the alternatives analysis indicates other technologies should be considered, the scoping test should include these additional technologies.

Response: Agree. The treatability test plan will define the performance of the EC system. If the test is successful, the system will be expanded and optimized to address the entire plume using extraction and injection wells.

- Try to utilize existing expertise in industry to minimize training costs. On-site training would be beneficial to the workers who would actually operate the system. (see reviewer 2)

Response: Comment noted.

Proposed Performance Metrics:

- Develop performance metrics for all aspects of the EC system design, including design specifications, vendor selection, effluent water quality, etc.

Response: Design specification will be developed and a vendor will be selected based on the FH procurement system. Performance criteria will be stipulated in the treatability test plan. Many of the criteria noted below are applicable.

- Performance metrics should report increased flow rate and Cr(VI) concentration reduction (<20ppb).

Response: Agree.

- Demonstrate operational reliability and safety of the EC system equipment.

Response: Agree.

- Measure pressure and flow data to monitor the operation of the EC system.

Response: Agree.

- There will be some interaction with soil, so predictions about when the system is finished may have to be extended to allow further time to remove Cr(VI) from solids.

Response: The shutdown criteria for the pump and treat for the 100-HR-3 is defined in the RDR/RAWP. These criteria will be used to shut down the system, assuming the EC is a viable technology to clean up the chromium plume. Rebound studies after shutdown are part of the evaluation for successful shutdown of any pump and treats system.

Specific Engineering and Design Recommendations

The electrocoagulation unit(s) should have the following to provide a very versatile system, to cover the anticipated variability of the treatment requirements, and have operation with minimum operator oversight:

Response: The design team will consider these requirements in their design criteria documents. Overall, we agree with the recommendations, except as noted.

- 1) The capacity to allow uninterrupted collection of water and be continuous at a rate independent of but less than the system's treatment capacity
- 2) Have the capacity to function between ~250 to 500 gpm and be modular in design (have at least two high flow easy accessible cartridges) to allow uninterrupted changing of electrode plates without stoppage of the unit but possibly with reduced flow

Response: The initial EC test is designed up to 50 gpm with the idea that it can be expanded. The expansion of the EC would consider item 2 recommendations.

3) The EC system should have built-in versatility of electrode arrangement to accommodate the field flexibility needed to treat the water at the Hanford 100-D Area. The system's electrode arrangement should be made easy to change in the field and have provisions for very rapid change-out of plates by cartridge design and mechanical devices that remove and replace cartridge as a unit and without removing flanges and bolts to the extent possible.

4) Have a de-foam tank that has the capability of adding coagulation polymers or not; which may fit with the integrated plan to add bio-nutrients to the plume for added reducing capacity

Response: This test will not include this feature. Subsequent up scaling may consider bioaugmentation.

5) Have a water clarification system (possibly based on slant-plate technology) for the clarifiers that is low corrosion with the capability of adding coagulation polymers or not; which may fit with the integrated plan to add bio-nutrients to the plume for added reducing capacity

Response: This test will not include this bio feature. Subsequent up scaling may consider bio augmentation.

6) Allow treated water to be discharged by gravity or pumping back to injection wells in the drain field.

7) Allow protection of the reducing capacity (avoidance of uncontrolled exposure to air) of the EC treated water to be sent to injection wells (this could use a physical or nitrogen blanket for example)

Response: This feature may be consider in future up scaling.

8) Be adjustable to control the rate of production not to exceed the injection well reception capacity if necessary

9) Allow the solids to be automatically and efficiently collected in a filter press hopper with liquid discharge from the clarifier or similar device

10) Meet National Electrical Code safety requirements in all respects. Ensure vendors use a system that operates below 40 volts; higher voltage systems present safety and electrical code concerns.

11) Be mountable on a prepared concrete or other surface with some protection against spills

12) Have the capability of rapid infield changing of the electrode arrangements from monopolar to bipolar and with variation of anode and cathode surface areas.

13) If DC, have the capability of automatic reversal of electrode polarity to prolong electrode life (avoiding reversal with contacts under load)

- 14) Will include electrical distribution and automated controls for minimum operator attention.
- 15) Have electrodes that are simple plates that can be changed without special tools or welding
- 16) Have provisions that allow the system power supply (rectifier) to be capable of maintaining the selected amperage even if the conductivity of the water changes by a considerable degree to avoid excursions or lack of treatment as various changes occur in the water
- 17) Have capability to run reliably for a long periods at high duty cycle.